FREEZING OF WATER IN SUBAQUEOUS MAINS LAID IN SALT WATER AND IN MAINS AND SERVICES LAID ON LAND[1]

By William Whitlock Brush

The writer recently stated his experience with salt water as a protection against the freezing of water in mains, and this was followed by a request to develop the subject more fully, including the principles governing the freezing of water in mains laid in salt water and also those laid on land. This paper is prepared in the hope that it may lead to a discussion of this subject and the setting forth of experiences which will be helpful to water works engineers and superintendents.

ICE FORMATION

The transformation of water from the liquid to the solid state, known as ice, as a result of the abstraction of heat from the water; is a process familiar to all, but the exact conditions under which such transformation takes place are not so generally known. This withdrawal of heat may be by means of radiation, conduction or convection, the transfer of heat being accomplished by any one of these agencies operating singly or in combination.

Radiation is the transmission of heat by waves. The earth thus receives its heat from the sun and this heat is in turn radiated from the earth. The sun's rays are shorter than those from terrestrial sources, and will pass freely through certain mediums, such as glass, which are fairly opaque to the longer heat waves from the earth. The color of the body on which the rays strike affects materially both the power of absorption of the waves and the rapidity with which heat is radiated from the body. A black surface most perfectly absorbs and remits heat waves. Radiation of heat has an important bearing on the formation of ice, as will be shown later.

Conduction of heat is a very slow process as compared with radiation and represents heat transfer from one body to another, by con-

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tact. Metal has a very high conductivity as compared with ice and water, their relative conductivities, assuming 1 for water, is 4 for ice and 120 for iron. The high conductivity of iron results in its rapid cooling when in contact with cold air and the conduction of heat from the water in a pipe line through the iron to the air. It is popularly supposed that ice is a much poorer conductor of heat than water. While this is not scientifically true the formation of an ice ring inside of a water main affords protection from a continuance of the freezing process. This is due to the ice ring having a conductivity only one-thirtieth of that of iron, and therefore materially retarding the withdrawal of heat from the water by conduction. Before the ice ring forms the heat in the water is conveyed to the iron through the movement of the molecules of water while the iron carries it to the outside of the pipe by conduction. This process takes place rapidly until the ice ring forms, when the heat in the water can only reach the air through both the ice and iron as conducting mediums.

Convection is the transmission of heat through the movement of the liquid due to a change in temperature, and is caused by a change in density which takes place with such change in temperature. It is well known that hot water is lighter than cold water, and as a result, rises to the surface. In case the air, metal or other substance in contact at the surface or high point is cooler than the liquid, heat will be given off either through conduction or radiation, or both. This process will continue until there is a temperature equality throughout the mass, which in nature seldom if ever takes place. There is therefore almost constant movement of liquids due to temperature differences and the resultant transmission of heat by convection.

Fresh water increases in density as the temperature is lowered, until a maximum is reached at 39° F. There is then a gradual reduction in density to the temperature of 32°, when the liquid changes to the solid form, known as ice, with a specific gravity of 0.89. It is this transformation that is particularly interesting to water works men, and some of the more important features of such transformation will be briefly discussed. The temperature of water is remarkably constant while ice is forming or melting. The temperature of the air may be many degrees below zero, but the temperature of fresh water, even though it be in a rapid running stream, will not be more than 0.01 below 32° F. Again, as long as there is

ice in the water the temperature will only be a similarly small fraction of a degree above 32°F., even though the temperature of the air be many degrees above the freezing point. A mixture of ice and water forms the most constant temperature known to physicists.

It is popularly believed that running water may be lowered to a temperature of several degrees F. below the freezing point before ice will be formed. This is an error. Absolutely still water may be cooled to approximately 10° F. below the freezing point without ice forming, but as soon as there is the slightest agitation of the water an immediate formation of ice takes place and continues until the heat released by the change from water to ice warms the remaining portion of the water to the freezing point. The latent heat of water at the freezing point is large, amounting to 80 calories per gram, or sufficient to raise 143 pounds of water 1° F. for every pound of water changed to ice.

Ice is divided into three kinds, based upon the manner in which it forms, i.e., surface ice, frazil ice and anchor ice.

Surface ice is the common form which appears on the surface of the water when the temperature of the water is cooled to the freezing point. It appears first near the shore and gradually extends out as the deeper water is cooled, the entire surface being eventually covered after the temperature of air remains below the freezing point for a sufficient period to cool the entire surface water to just below 32° F. After the ice is formed, the thickness increases, mainly through the conduction of heat from the water through the ice, it being necessary to conduct not alone the heat in the water but also the latent heat previously in the water, which is released as the water changes to ice. As the conductivity of ice is low, being only one thirty-second of that of iron, this process is relatively slow and the thicker the ice sheet the slower the increase in depth of ice.

Frazil ice is the form which appears in running water when the temperature of the water falls below 32° F. and where an ice sheet cannot form due to the agitation of the water. It forms at the surface and may be made up of flat plates, if the surface is not greatly agitated, but more frequently is in the form of minute needle crystals which join together and form a bulky mass, floating lower in the water than the ordinary surface ice.

Anchor ice is ice which is found attached or anchored to the bottom of a river or a stream, and results from the cooling of the

material at the bottom of the river by radiation, and the resultant freezing of the water which comes in contact with the surfaces, which have been cooled below the freezing point. It will only occur under a clear sky and where there is nothing to interfere with the process of radiation. As dark objects radiate heat more rapidly than light colored ones, anchor ice will form more rapidly on a dark stone than on a light one. It will not be formed under a bridge where radiation is interfered with, nor under ice, which also prevents radiation. When the sun's rays strike the masses of ice, earth and stone, they are absorbed and frequently the whole mass will become loosened and float to the surface. Large rocks are thus raised and carried down stream with the ice.

These three forms of ice are all of interest to the water works engineer, not alone as affecting the problems to be met at the source of supply, when such source may be a reservoir or stream, but also in the distribution of water, as will be shown later.

It is generally considered that ice is a poorer conductor than water. This belief is probably founded upon the very material protection which ice or snow gives against frost penetration. Such protection is mainly due to the resistance of ice and snow to the transmission of the heat waves of radiation. Clear water offers little resistance to the radiation of heat, but is a very poor conductor of heat. Due to the difference in density of water at different temperatures, water will transmit heat through convection, or the movement of the molecules, much more rapidly than will ice, by conduction. The molecules of ice are unable to move freely, and transmission of heat through ice, by convection, is therefore negligible.

Pressure lowers the temperature at which water changes to ice, but its effect is very slight, thus, a pressure of 1 pound per square inch will lower the freezing point 0.009° F. Assuming the normal pressure in a water main to be 40 pounds per square inch, the lowering of the freezing point by such pressure would amount to less than 0.04° F.

The introduction of certain chemicals into the water lowers the freezing point. The most common chemical found is salt, and all are familiar with the lowering of the freezing point caused by the presence of salt. The volume of salt determines the temperature at which the ice forms, the salt being thrown out by the crystallization of the water, so that ice formed in salt water is fresh. The

ordinary sea water will freeze at about 27° F. and the temperature of the water is therefore well below the freezing point of fresh water. As the percentage of salt in the water decreases, the freezing point rises, but this freezing point is probably below 30° F. in the tidal waters surrounding our sea-board cities.

FORMATION OF ICE IN WATER MAINS

The formation of ice in water mains is dependent upon the temperature of the water in the main and the velocity of current, the pressure being of negligible effect, as has previously been shown. It is probable that the water as drawn from a reservoir or stream is seldom below 33° F., as the formation of ice and the density of the water generally prevent the cooling of the water below this temperature. If the water in passing through the main is not reduced in temperature to below 32° F. there will be no danger of freezing. If it is reduced below 32° F. ice will begin to form, the ice forming a coating on the inside of the pipe, due to the high conductivity of the iron. As the ice film thickens, the transmission of the heat of the water to the surrounding earth and thence to the air is greatly retarded, the conductivity of ice being such a small fraction of the conductivity of the iron. If the velocity in the main is reduced through a lowering of the rate of draft, the water in the main is more readily cooled, and the rate of ice formation correspondingly increases. This ice formation may be properly classified as surface ice. It is probable that in a main where the velocity is high, the water is cooled slightly below the freezing point and a form of frazil ice created. Such ice might eventually clog the main, stopping the flow, and the whole mass of water in the main quickly change to solid ice. In the report of the Committee of the New England Water Works Association on the depth at which mains should be laid to prevent freezing, submitted in 1909, reference is made to slush ice forming in a main laid in a salt marsh at New Brunswick, New Jersey. The velocity in this main was high and frazil ice probably formed. A stoppage in flow may also occur after a thaw, due to the loosening of the film of ice which has formed during the cold spell, and which may break up and flow through the water until it reaches a point in the main where the ice may not have broken loose and where the floating ice will become packed in such a manner as to completely stop the flow. While this might

account for the stoppage of flow in mains, especially in house services, after a thaw, which is an experience not uncommon to water works superintendents, there is a record of an actual reduction in temperature of soil below 32° F. following a thaw, and such reduction would be ample reason for the freezing up of water mains coincident with a thaw.

PREVENTION OF FORMATION OF ICE IN SUBAQUEOUS MAINS

Where a main is laid in salt water it is common practice to lay the main without any earth cover. The iron is therefore exposed directly to the salt water, which is usually in motion, and heat may be rapidly abstracted from the water in the main through the three agencies of transmission, i.e., radiation, conduction and convection. Radiation is active in clear water and especially so from the black pipe. The iron is also an excellent medium for conduction, with the heat being absorbed from the surface of the iron by the water flowing over the pipe. Convection will readily do its part within the pipe. The temperature of the salt water, during a period of severe cold, may be lowered several degrees below the freezing point and under such conditions ice will form in the water main and the main will be completely clogged, unless the rate of flow is sufficient to maintain the temperature at the discharge end of the main, at or above 32° F. If a main is laid in a body of fresh water, there is little danger of freezing, except at the point where the main enters the water, as the temperature of the water will be above 32° F. and a covering of surface ice will prevent excessive radiation. If the main is laid in the bottom of a rapidly flowing fresh water stream, it is possible that through radiation and the cooling of the water in the stream, ice might form in the main, but it is improbable that such ice would be of sufficient thickness to interfere with the delivery of water through such main.

EXPERIENCE IN FREEZING UP OF A SUBAQUEOUS MAIN LAID IN SALT WATER AND USE OF ELECTRICITY TO THAW OUT THE MAIN

In February, 1912, New York and vicinity experienced a very cold spell, which commenced on February 3, and continued until February 15. The severest cold was experienced from 11 p.m. on February 9 to 11 a.m. on February 13, the temperature for the first

thirty-six hours of this period ranging from 14° F. to −1° F. During the night of the 11th–12th, the temperature averaged about 13° F. At 9 a.m. on February 12 word was received at the South Bronx Repair Company's headquarters that there was lack of pressure at North Brothers Island. This island is located about 1800 feet from the borough of The Bronx shore, opposite 132d Street. At that time the island was supplied with water by a 6-inch main, 1760 feet in length, laid in 1888, the general depth of the water being 70 feet. This line was exposed at low tide for a distance of about 150 feet from the North Brothers Island shore. An auxiliary line, 12 inches in diameter and 29,700 feet long, was laid in 1906, from Riker's Island to North Brothers Island, Riker's Island being supplied from the mainland by a 12-inch main. The average depth of water in which the 12-inch main was laid was 30 feet. When it was found that the water pressure was reducing, effort was made to increase the flow by opening a fire hydrant and by operating a pump on the island, that was connected to the water main. The evidence at the time pointed to trouble existing both in the 12-inch main and in the 6-inch main. On the morning of February 13, the supply to the island was entirely stopped, and it was not resumed until March 12. At the time of stoppage there had been an extremely low tide and the 6-inch pipe line on the North Brothers Island shore had no cover except rip-rap.

The first trouble was experienced a day and a half after the beginning of the extreme cold spell, and the final stoppage of the main was two and a half days thereafter. The nights during this period were clear, while the days were partially cloudy. The wind was from the north and northwest, with a maximum velocity of 22 miles an hour. The temperature of the river was not taken at this time, but a week later, the weather in the interval remaining at about freezing point. The temperature in the river at a depth of 50 feet was found to be 29° and 32° on the surface. It is probable that the river water was at a lower temperature than 29° when the main was frozen. The weather conditions were ideal for radiation of heat from the main. The temperature of water in the pipe, before it entered the river, was about 34°, this being the recorded temperature of water from the same source that had traveled an equal distance underground. On the main shore end of the pipe, frost was in the ground to a depth of 39 inches, which was 3 inches below the bottom of the pipe.

Effort was made to thaw out the main by building fires around the exposed portion, and using steam hose. A tap placed on the main showed that the main was frozen solid below tide level. As all efforts to thaw the main by ordinary means failed, and as there were about 500 people on the island, mainly patients in a hospital, who could only be served with water transported on boats from the mainland, arrangements were made with the Edison Electric Company to thaw out the main, using electricity. This company started work on March 6, and on the morning of March 7, a current of about 800 amperes at 200 volts was passed through the main, using four 100 kilowatt transformers to step the current from 2000 volts down to 200. During that evening the current was increased to 1000 amperes, on the 8th to 1300 amperes, and on the morning of the 9th, to 1500 amperes and 400 volts, two more 100 kilowatt transformers having been installed. At noon on the 10th, the current was increased to 1800 amperes at 368 volts. As the ice failed to melt, an experiment was tried, a length of pipe being packed solid with ice, closed tight at both ends, and let down to the bottom of the river, and the same current passed through it as was passed through the main. After twelve hours the ice was found to be entirely melted. The current was continued until 6.20 a.m. on Tuesday, March 12, and without any previous warning the water started to flow from the mainland end of the pipe. During the time the current was on, 1000 horse power had been used, it being estimated that thirty-six times as much heat had been generated to melt the ice in the North Brothers Island main as would have been required to melt the same quantity of ice on land. The rapid transmission of the heat from the pipe to the cold water flowing over the pipe was the cause of the failure of this method to thaw out the pipe. On March 12, the date when water started to flow, the temperature of the water was 32°. On the same day the pipe line from North Brothers Island to Riker's Island thawed out, from natural causes.

On March 10, it had been clear throughout the day and night and the temperature had reached 86° in the sun, the maximum in the shade being 41°, the minimum 33°, with an average of 32°. Under such conditions there would be a very material absorption by the water main of heat, through radiation, and with the temperature of the river water up to the freezing point it is possible that the electric current had little effect on the thawing of the

main, although the heat generated by the current was noticeable on the shore ends of the pipe. There is no clear indication of the effectiveness of the electric current thawing the main under the conditions cited.

FROST PENETRATION ON LAND

The Committee of the New England Water Works Association, which reported in 1909 on freezing of water mains, stated in their report that they had received 90 replies from 320 circulars sent out to water works engineers and superintendents, 53 communities had had trouble with freezing of mains, 50 per cent of the freezing had occurred at dead ends, and in all cases there had been little or no velocity. In all but three cases the mains were smaller than 10 inches in diameter, and only seven as large as 8 inches in diameter. In every case the ground was frozen below the axis of the pipe. Forty per cent of pipe was laid in clay, 48.6 per cent in gravel, 5.7 per cent in sand and 5.7 per cent in rock. The depth of penetration of frost was found to be 1 foot greater in the streets than in the fields, and 1 foot 5 inches deeper in gravel than in clay, the depth in sand being about midway between the depth in clay and in gravel. The ice was found at times in concentric rings in pipe as large as 24 inches in diameter, and no stoppage of the pipe had occurred. The ice formation was not always solid, but sometimes in the form of slush. The depth of frost penetration varied materially. The committee called attention to a belief or tradition that existed in the minds of many plumbers and water works superintendents, that most stoppages occurred during a thaw, following a period of severe cold weather, it being suggested that this might be caused by evaporation from the surface during the early stages of the thaw, producing additional refrigeration or reduction of temperature at the depth of a water main sufficient to cause freezing. The committee comment that the reports received did not support this theory. In the discussion of the report an instance was cited where a pipe was laid in the late fall in rock cut, and the backfilling was composed of frozen earth and rock, giving a very porous filling. A comparatively slight current was maintained in the pipe. In the early spring, on a day when it was warm enough so that it was comfortable to be about in shirt sleeves, the pipe stopped up. It was left until the following morning, when it was found that the pipe was again clear.

Mr. Jesse O. Shipman, division engineer, public service commission, New York City, states that, where services are run through bays in the subway, where, in general, the distance from the surface of the ground to the service is about 4 feet, with 6 inches of earth below the service and 12 inches of concrete forming the roof of the subway, trouble from the service clogging with ice usually occurs a day or so after a thaw, following a severe cold spell, has set in.

The writer endeavored to find records of ground temperature but was able to locate only those of Profs. H. L. Callendar and C. H. McLeod of McGill University, Montreal, Canada, and recorded in the proceedings of the Royal Society of Canada for the years 1895, 1896 and 1897.

These experiments were started in 1894 by Professor Callendar and he was later assisted by Professor McLeod. The location selected for the experiment was level ground in a garden where there was turf and loose light brown sand to a depth of 8 feet 6 inches. Below this sand was stiff blue clay to a depth of 30 feet from the surface. Water was found in the sand for some distance above the clay but the sand was nearly dry to a depth of 5 feet.

A trench 3 feet wide and 9 feet deep was dug, with one face vertical. Into this face horizontal holes were bored for nearly 3 feet, using a one-half inch rod. Electrical resistance thermometers, consisting of a carefully insulated coil of platinum wire about 3 inches long and protected by an external tube of glass or copper, were inserted in these holes and connected to the indicating apparatus by insulated leads of convenient length. The holes were bored at depths of 1, 4, 10, 20, 40, 66 and 108 inches. In the earlier periods readings were taken daily at 12 noon, but later a continuous recording apparatus was installed. An abstract of the snow conditions and temperatures recorded will be found on pages 972 and 973.

This record shows very clearly the material effect of snow on the depth of frost penetration and the slight cover probably required when snow is always present early in the winter. The record of the thermometer buried at a depth of 10 inches, which showed in April, 1895, a drop of 0.2 to 0.3° below 32°, which was the temperature at the beginning of the thaw, is very interesting. This shows that a lowering of the ground temperature below 32° F. may result from a thaw. The following notes are copied from the text:

Winter 1894–1895

DEPTH OF THERMOMETER	PERIOD TEMPERATURE WAS BELOW 32° F.	MINIMUM TEMPERATURE	SNOW CONDITIONS
Air	Dec. 20 to Mar. 20	−10° F. in Feb.	10 inches snow Dec. 28 which increased to 21 inches by Feb. 1, 33 inches by Feb. 7. Began to melt in March. Final melting of snow between Apr. 7 and 14
1 inch	Nov. 25 to Apr. 14	27° F. in Dec., just before snow fall	
4 inches	Nov. 28 to Apr. 14	28° F. in Dec., just before snow fall	
10 inches	Dec. 16 to Apr. 14	31½° F. in Dec., just before snow fall	
20 inches	0	33°F. Dec. 14, melting snow	
40 inches	0	35½° F. Apr. 20, melting snow	
66 inches	0	38°F. Apr. 21, melting snow	
108 inches	0	41½° F. Apr. 22, melting snow	

Winter 1895–1896

Air	Nov. 20 till Apr. 10 except for short rises	−15° F. Feb. 18	Practically no snow till Jan. 24. The winter is remarkable for lateness of heavy snow fall and for the rapidity of its disappearance. Light snow fell in Nov. and Dec. disappeared. Heavy snow fall commenced Jan. 24 and increased to maximum of about 30 inches in March. Snow disappeared about April 12
1 inch	Dec. 2 to Apr. 20,	27° F Jan. 22, before snow fell	
4 inches	Slightly shorter period than for 1 in.	28° F. Jan. 22, before snow fell	
10 inches	Dec. 22 to Apr. 20,	30° F. Jan. 22, before snow fell	
20 inches	0	32½° F. Jan. 23	
40 inches	0	34½° F. Apr. 15, melting snow	
66 inches	0	38°F. Apr. 20, melting snow	
108 inches	0	41° F. Apr. 25, melting snow	

The final thawing of the ground took place at a depth of 10 inches on April 19. The 10 inch thermometer which had remained within less than 0.1° F. for about two months previously, showed a depression of 0.3 when the thaw reached it, probably due to lowering melting point by dissolved salts. . . . . The percolation of water caused a slight simultaneous fall in the two thermometers next below.

Winter 1896–1897

DEPTH OF THERMOMETER	PERIOD TEMPERATURE WAS BELOW 32° F.	MINIMUM TEMPERATURE	SNOW CONDITIONS
Air	Nov. 15 to Mar. 20	Mean temperature air Dec. 23, 5° F.	No snow during early part winter; frost penetrated much deeper into soil than during two years previous; thawing of ground after disappearance of snow was lengthy operation; 20 days were required. Temperature at 20 inches did not rise above freezing till May 1
1 inch	Nov. 23 to Apr. 3	10° F. Jan. 20	
4 inches	Dec. 1 to Apr. 10	12° F. Jan. 20	
10 inches	Dec. 15 to Apr. 18	19° F. Jan. 20	
20 inches	Jan. 5 to Apr. 25	27° F. Jan. 20	
40 inches	Nearly reaches 32° F. during Mar. and April	33° F. Mar. and Apr.	
66 inches	0	36° F. Apr. 22, melting snow	
108 inches	0	39° F. May 2, melting snow	
			First fall of snow quite light Dec. 5. Practically no snow till Jan. 20. About 20 inches snow on ground from Jan. 20 to Feb. 20. About Feb. 20 snow increased gradually and uniformly to about 28 inches by Mar. 1. Snow disappears about Apr. 2 or 3

This record obtained in a carefully conducted experiment is confirmation of the possibility of a thaw causing the freezing of water pipes. The rapid lowering of ground temperature by cold water percolating through the ground was strikingly shown several times during the period covered by the records. While percolating waters may lower the temperature, the presence of moisture reduces the likelihood of services freezing, for the following reasons:

(a) The freezing of the water releases latent heat which is transmitted to the ground.

(b) The frozen ground is a poor conductor of heat.

(c) Water is a poor conductor of heat, and when it is held in the ground by the action of capillarity, it cannot readily conduct heat by convection, as it would if it were free to move.

PREVENTION OF FORMATION OF ICE IN MAINS AND SERVICES

Where frost penetration has extended to, and possibly beyond, the level at which a water main or service has been installed, the water in the main or service will freeze unless the temperature of the water in such main is kept at or above 32° F. This can only be accomplished by having such quantity of water pass through the main that the rate of abstraction of heat will not be sufficiently rapid to cause the temperature of the water to fall below 32°.

As has been pointed out, in the supply from the Croton River, the temperature of the water, even during a very cold spell, is found to be about 34°. As long as there is sufficient water passing through the mains to prevent this temperature being reduced by more than 2°, i.e., to 32° F., there will be no danger of freezing of water in the mains. By testing the temperature of the water as it is drawn from a hydrant, it can be determined whether there is or is not likelihood of the main freezing. No rule can be formulated which would answer the question as to whether a main will freeze under given conditions. A protecting covering is certainly a great aid in reducing the danger of freezing, and snow on the ground is an almost sure preventive.

THAWING ICE IN MAINS AND SERVICES

The problem of thawing out frozen mains and services has been greatly simplified through the utilization of the electric current at low tension. While it was found that this method was not of much value when applied to a main laid in water, where the heat generated through the passage of the electric current would be rapidly dissipated by the flowing current of water, the condition where the pipe is covered with soil is entirely different and much more favorable to the thawing of the main. As the electric current passes through the metal, the heat generated will thaw both the ice which is formed within the main and the ice which is formed in the soil outside of the main. The transmission of this heat to the

surrounding earth and thence to the surface is very slow and a comparatively small amount of current is required to make the necessary change from ice to water. It is not necessary to describe the actual application of electricity to the mains as this has been set forth in detail many times.

The writer found in his investigation of this subject that a study of the formation of ice in streams has greatly aided him in obtaining a clearer conception of the conditions under which ice is liable to be formed in mains, and on this subject he has drawn freely from the "Treatise on Ice Formation," by Howard T. Barnes, Associate Professor of Physics, McGill University, Montreal, who has made extensive experiments and observations on ice formation in the St. Lawrence River and elsewhere.

DISCUSSION

Mr. C. R. Wood: Will Mr. Brush tell us whether in his studies of ice action he ran across any theories as to the melting of ice At Eaglesmere, Pennsylvania, where Mr. Emery's plant is located, the ice, which is cut at a temperature well below zero, as a rule does not melt nearly as fast in household use as the ice supplied in Philadelphia, whether it is manufactured or natural ice cut in Pennsylvania, near Philadelphia.

Mr. William W. Brush: There would be a difference in the rate of melting of ice that was cut at a very low temperature. If the ice itself was materially below the freezing point, it would be very much harder, as ice at the lower temperatures is much harder than ice at the higher temperatures. It will also require the absorption of a certain amount of heat to bring the ice up to the melting point, although that heat is rather small compared with the heat which is absorbed in the change of structure from ice to water. The difference in the rate at which ice that had been cut at the low temperature would melt as compared with the ice that had formed at ordinary outdoor temperatures would be rather small. Artificial ice is cooled only very slightly below 32°, and so it is in a condition where it would probably change very quickly to water. It would be very interesting to get statements as to the conditions under which ice has formed and the character of ice. Personally, the speaker has had very little experience with cutting mains when

they were frozen and examining the ice in them. In the case of the pipe under the East River, there would be no question but that the ice would be very solid, because that main had been exposed many days to a temperature of 29° without any flow of water through it. The condition under which slush ice has stopped up the mains, and the appearance of the ice when examined, would be very interesting, and also the experience of those present at the freezing of mains after a thaw. The speaker does not know whether the theory set forth is the correct one as to the stopping up of the mains, but it would only be by obtaining the experience of the different men in the freezing of mains that we could hope to get the correct theory as to the stopping of services after a thaw, which is a matter interesting to a good many of us.

MR. CARLETON E. DAVIS: Have you any set of questions that might be sent out to get a wide range of answers? Could you suggest any change from the New England Water Works Association questions?

MR. WILLIAM W. BRUSH: The New England Water Works Association questions were directed mainly to the question of depth of cover. They were not directed to the question of the formation of ice from the viewpoint of the character of ice formed. If questions were to be sent out, a different line of inquiry would be developed by such questions from the line of inquiry developed by the New England Water Works Association Committee. The speaker has not up to the present time given that matter any personal consideration, but it might be interesting to have an inquiry sent out to obtain all information that could be developed as to the way in which the ice was formed, and the character of ice noted when the main was cut, in case any of the mains have been cut when frozen.

MR. GEORGE S. CHEYNEY, JR.: The speaker has had a little experience along this line. We have a reservoir holding 2,000,000 gallons; this is about 10 feet deep and there is a 12-inch inlet pipe and a 20-inch outlet pipe passing under the reservoir embankment. The reservoir is constructed of earth embankment, about 10 feet wide on top with an extreme height of probably 15 feet, with 1½ to 1 slopes, so that there is about 50 feet of width of embankment at the bottom. A short distance from the outside of the embank-

ment a gate house is located, with a basement approximately 10 feet deep. The inlet and outlet pipes referred to, pass through the basement of this gate house, and on the outlet pipe there is located a wrought iron screen pot, about 3 feet in diameter. The screen in this pot has been choked up with something like slush or anchor ice on three different occasions in the past eight years. The first time it was reported the surface of the reservoir was found to be covered with unbroken ice which was several days old. At the time of this trouble the flow from the reservoir was practically stopped by the ice and an examination showed the upper half of the screen pot to be practically filled with ice. The next trouble occurred two years ago and at that time there was no ice on the reservoir. There had been a very heavy snow squall in the afternoon with a high wind blowing toward the gate house; probably 2 or 3 inches of snow fell in fifteen minutes. The screen was again choked up in the same manner a few hours after this, and the trouble at that time was attributed to the saturated snow which it was thought had been blown over to the side of the reservoir next to the outlet pipe, and carried into the screen pot. The third trouble occurred last winter, when the reservoir was covered with a heavy cake of ice several days old. The anchor or slush ice was again found in the screen pot, and practically stopped the flow. The chamber in which this screen pot is located is about 10 feet deep, all below the ground level, and at about the ground level there is a cement floor, so that it is well below the frost level. The gate house is of masonry, about 18 feet in diameter, which makes it seem impossible that there should be any freezing in the screen pot itself, on account of its location. A number of small pipes and gate valves with bonnets in the same chamber have never caused any trouble from freezing. There are about thirty similar reservoirs under the speaker's charge and this is the only one where trouble of this kind has been experienced. The reservoir is located on the top of a hill in an exposed position, where it gets the northwest winds, but it is no more exposed than many others where no trouble is experienced.

Mr. William W. Brush: Are the other reservoirs of a greater depth?

Mr. George S. Cheyney, Jr.: They are practically the same, probably 15 feet depth of water at the outlet. The reservoir referred

to is 40 miles west of Philadelphia, where we do not have very extreme temperatures.

Mr. William W. Brush: The formation of ice under those conditions would necessarily come from the water being very nearly, if not quite, at 32° temperature at the time it enters the chamber, and a chilling in the chamber. It would be very interesting to know what the temperature was in the chamber at the time, because it was so clearly shown in the St. Lawrence River experiments that the water must be chilled below 32°, but it will not be chilled more than 0.01° F. before the frazil ice or the slush ice will form, so if there is anything at this reservoir that would cause that very slight cooling of the water, slush ice would form in the valve chamber.

Mr. George S. Cheyney, Jr.: Would you not expect it to freeze around the outside of the chamber forming a coating, rather than to form slush ice?

Mr. William W. Brush: In the chamber the agitation and velocity were probably sufficient to prevent forming of a coating. Did the slush ice form before it struck the screen or at the screen?

Mr. George S. Cheyney, Jr.: The screen divides this chamber into two equal parts. Most of the ice, of course, is on the screen, but apparently the whole upper part of the screen pot was more or less filled with slush ice.

Mr. William W. Brush: It would seem as though that must have been chilled by the exposure to the air at that point.

Mr. George S. Cheney, Jr.: A 20-inch pipe line on a bridge exposed for a length of about 2000 feet is covered with the usual covering and we have been thinking of dispensing with this covering, and made some experiments to determine the temperature of the water in the pipe line at the ends of the bridge, using recording thermometers. These experiments were not very satisfactory on account of the inaccuracy of the thermometers. In connection with this we made some rough laboratory experiments to determine whether water at 32° F. flowing through an exposed pipe line would retain enough heat units to prevent it from freezing. The experi-

ment was made by sinking a thin metal vessel containing water in a larger vessel containing brine at zero temperature. The water in the inner vessel was kept constantly stirred and its temperature fell to 32° F. where it remained and no freezing occurred except a ring around the outside which was in contact with the metal. This ring of ice gradually increased in thickness while the water in the center of the vessel was kept in its liquid state. The experiment seemed to prove that a ring of ice could be formed on the inside of the pipe through which water is flowing even though the water itself contained sufficient heat units to prevent freezing.

Mr. William W. Brush: That would be true. The water in direct contact with the mains would probably freeze first in any main and form a film of ice inside of the main. Then if the intensity of cold were sufficient to lower the temperature of the water inside of the main, inside of this ice coating, to just slightly below 32°, even though there was comparatively high velocity, this frazil ice would be apt to form.

Mr. George S. Cheyney, Jr.: In the experiments the only ice that formed was a ring against the metal on the outside and that gradually increased in thickness. The water kept constantly at 32° F.

Mr. William W. Brush: Professor Barnes states that he tried the experiment and produced in the laboratory this frazil ice by agitation of the water, and it would freeze on the inside of the vessel which was exposed to the extraordinarily low temperature of water outside, but he produced the frazil ice, rather than the solid ice, in the laboratory.

Mr. George S. Cheyney, Jr.: That would be a question of radiation, if the radiation were rapid enough to keep the water temperature down to 32°, you would not get the frazil ice?

Mr. William W. Brush: You would not; you would have to have rather rapid radiation and get the water just super-cooled or slightly below 32°, and then the frazil ice would start to form. The case mentioned, which was reported in New Brunswick, seems to be the nearest to the formation of true frazil ice in a water main

where it was in salt water and where it filled with slush ice at a comparatively high velocity through the main.

Mr. Carleton E. Davis: The speaker recalls one instance where frazil ice performed a good service. The Newark Water Works has two lines of steel pipe. One very cold winter night the supply was cut off. It was found that ice had accumulated on the racks at the intake to such an extent it had cut the water off. There was no way of removing the ice, so they pulled up the racks and let the ice go down into the pipes. That pipe was badly tuberculated, the frazil ice removed all of this tuberculation, thereby increasing the carrying capacity 5 per cent.

Mr. Earle W. Meckley: When investigating the pipe going over to North Brothers Island did you notice any greater heating of the water at the change of tide? You said at the ends of the pipe you noticed the heating of the water when the electric current was applied. Was there any greater effect in the heating of the water when the tides changed, because then there could not be that rapid conduction of hot water from the outside of the pipe by the flow of the water?

Mr. William W. Brush: That raises a point which was not investigated at the time. It would be interesting to see whether at about the time the ice gave way in the main there was a change in the tides. There would undoubtedly be a greater effect in the passing of the electric current through the main at the slack tide, but the department did not have any means of accurately measuring the temperatures, and only attempted to get a rough determination of the temperature of the water in the river to see whether it was low enough to be responsible for the freezing of the main.